



# **Distillation Troubleshooting**

**Henry Z. Kister**

*Fluor Corporation*

**AIChE®**

 **WILEY-  
INTERSCIENCE**

**A JOHN WILEY & SONS, INC., PUBLICATION**

This page intentionally left blank

# **Distillation Troubleshooting**

This page intentionally left blank

# **Distillation Troubleshooting**

**Henry Z. Kister**

*Fluor Corporation*

**AIChE®**

 **WILEY-  
INTERSCIENCE**

**A JOHN WILEY & SONS, INC., PUBLICATION**

## DISCLAIMER

The author and contributors to "Distillation Troubleshooting" do not represent, warrant, or otherwise guarantee, expressly or impliedly, that following the ideas, information, and recommendations outlined in this book will improve tower design, operation, downtime, troubleshooting, or the suitability, accuracy, reliability or completeness of the information or case histories contained herein. The users of the ideas, the information, and the recommendations contained in this book apply them at their own election and at their own risk. The author and the contributors to this book each expressly disclaims liability for any loss, damage or injury suffered or incurred as a result of or related to anyone using or relying on any of the ideas or recommendations in this book. The information and recommended practices included in this book are not intended to replace individual company standards or sound judgment in any circumstances. The information and recommendations in this book are offered as lessons from the past to be considered for the development of individual company standards and procedures.

Copyright ©2006 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400, fax 978-646-8600, or on the web at [www.copyright.com](http://www.copyright.com). Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at [www.wiley.com/go/permission](http://www.wiley.com/go/permission).

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services please contact our Customer Care Department within the U.S. at 800-762-2974, outside the U.S. at 317-572-3993 or fax 317-572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print, may not be available in electronic format. For more information about Wiley products, visit our web site at [www.wiley.com](http://www.wiley.com).

### ***Library of Congress Cataloging-in-Publication Data:***

Kister, Henry Z.

Distillation troubleshooting / Henry Z. Kister.

p. cm.

Includes bibliographical references.

ISBN-13 978-0-0471-46744-1 (Cloth)

ISBN-10 0-471-46744-8 (Cloth)

1. Distillation apparatus—Maintenance and repair. I. Title.

TP159.D9K57 2005

660'.28425—dc22

2004016490

Printed in the United States of America

10 9 8 7 6 5

*To my son, Abraham and my wife, Susana, who have been my  
love, inspiration, and the lighthouses illuminating my path,  
and to my life-long mentor, Dr. Walter Stupin – it is easy to rise  
when carried on the shoulders of giants.*

This page intentionally left blank



# Contents

**Preface**      xxiii

**Acknowledgments**      xxvii

**How to Use this Book**      xxix

**Abbreviations**      xxxi

<b>1. Troubleshooting Distillation Simulations</b>	<b>1</b>
<b>2. Where Fractionation Goes Wrong</b>	<b>25</b>
<b>3. Energy Savings and Thermal Effects</b>	<b>61</b>
<b>4. Tower Sizing and Material Selection Affect Performance</b>	<b>73</b>
<b>5. Feed Entry Pitfalls in Tray Towers</b>	<b>97</b>
<b>6. Packed-Tower Liquid Distributors: Number 6 on the Top 10 Malfunctions</b>	<b>111</b>
<b>7. Vapor Maldistribution in Trays and Packings</b>	<b>133</b>
<b>8. Tower Base Level and Reboiler Return: Number 2 on the Top 10 Malfunctions</b>	<b>145</b>
<b>9. Chimney Tray Malfunctions: Part of Number 7 on the Top 10 Malfunctions</b>	<b>163</b>
<b>10. Draw-Off Malfunctions (Non-Chimney Tray) Part of Number 7 on the Top 10 Malfunctions</b>	<b>179</b>

<b>11. Tower Assembly Mishaps: Number 5 on the Top 10 Malfunctions</b>	<b>193</b>
<b>12. Difficulties During Start-Up, Shutdown, Commissioning, and Abnormal Operation: Number 4 on the Top 10 Malfunctions</b>	<b>215</b>
<b>13. Water-Induced Pressure Surges: Part of Number 3 on the Top 10 Malfunctions</b>	<b>225</b>
<b>14. Explosions, Fires, and Chemical Releases: Number 10 on the Top 10 Malfunctions</b>	<b>233</b>
<b>15. Undesired Reactions in Towers</b>	<b>237</b>
<b>16. Foaming</b>	<b>241</b>
<b>17. The Tower as a Filter: Part A. Causes of Plugging—Number 1 on the Top 10 Malfunctions</b>	<b>253</b>
<b>18. The Tower as a Filter: Part B. Location of Plugging—Number 1 on the Top 10 Malfunctions</b>	<b>257</b>
<b>19. Coking: Number 1 on the Top 10 Malfunctions</b>	<b>271</b>
<b>20. Leaks</b>	<b>281</b>
<b>21. Relief and Failure</b>	<b>287</b>
<b>22. Tray, Packing, and Tower Damage: Part of Number 3 on the Top 10 Malfunctions</b>	<b>291</b>
<b>23. Reboilers That Did Not Work: Number 9 on the Top 10 Malfunctions</b>	<b>315</b>
<b>24. Condensers That Did Not Work</b>	<b>335</b>
<b>25. Misleading Measurements: Number 8 on the Top 10 Malfunctions</b>	<b>347</b>

<b>26. Control System Assembly Difficulties</b>	<b>357</b>
<b>27. Where Do Temperature and Composition Controls Go Wrong?</b>	<b>373</b>
<b>28. Misbehaved Pressure, Condenser, Reboiler, and Preheater Controls</b>	<b>377</b>
<b>29. Miscellaneous Control Problems</b>	<b>395</b>

---

## DISTILLATION TROUBLESHOOTING DATABASE OF PUBLISHED CASE HISTORIES

---

<b>1. Troubleshooting Distillation Simulations</b>	<b>398</b>
1.1 VLE	398
1.1.1 Close-Boiling Systems	398
1.1.2 Nonideal Systems	399
1.1.3 Nonideality Predicted in Ideal System	400
1.1.4 Nonideal VLE Extrapolated to Pure Products	400
1.1.5 Nonideal VLE Extrapolated to Different Pressures	401
1.1.6 Incorrect Accounting for Association Gives Wild Predictions	401
1.1.7 Poor Characterization of Petroleum Fractions	402
1.2 Chemistry, Process Sequence	402
1.3 Does Your Distillation Simulation Reflect the Real World?	404
1.3.1 General	404
1.3.2 With Second Liquid Phase	406
1.3.3 Refinery Vacuum Tower Wash Sections	406
1.3.4 Modeling Tower Feed	406
1.3.5 Simulation/Plant Data Mismatch Can Be Due to an Unexpected Internal Leak	406
1.3.6 Simulation/Plant Data Mismatch Can Be Due to Liquid Entrainment in Vapor Draw	407
1.3.7 Bug in Simulation	407
1.4 Graphical Techniques to Troubleshoot Simulations	407
1.4.1 McCabe–Thiele and Hengstebeck Diagrams	407
1.4.2 Multicomponent Composition Profiles	407
1.4.3 Residue Curve Maps	407
1.5 How Good Is Your Efficiency Estimate?	407
1.6 Simulator Hydraulic Predictions: To Trust or Not to Trust	409
1.6.1 Do Your Vapor and Liquid Loadings Correctly Reflect Subcool, Superheat, and Pumparounds?	409
1.6.2 How Good Are the Simulation Hydraulic Prediction Correlations?	409

## 2. Where Fractionation Goes Wrong 410

- 2.1 Insufficient Reflux or Stages; Pinches 410
- 2.2 No Stripping in Stripper 412
- 2.3 Unique Features of Multicomponent Distillation 412
- 2.4 Accumulation and Hiccups 413
  - 2.4.1 Intermediate Component, No Hiccups 413
  - 2.4.2 Intermediate Component, with Hiccups 414
  - 2.4.3 Lights Accumulation 416
  - 2.4.4 Accumulation between Feed and Top or Feed and Bottom 417
  - 2.4.5 Accumulation by Recycling 418
  - 2.4.6 Hydrates, Freeze-Ups 418
- 2.5 Two Liquid Phases 419
- 2.6 Azeotropic and Extractive Distillation 421
  - 2.6.1 Problems Unique to Azeotroping 421
  - 2.6.2 Problems Unique to Extractive Distillation 423

## 3. Energy Savings and Thermal Effects 424

- 3.1 Energy-Saving Designs and Operation 424
  - 3.1.1 Excess Preheat and Precool 424
  - 3.1.2 Side-Reboiler Problems 424
  - 3.1.3 Bypassing a Feed around the Tower 424
  - 3.1.4 Reducing Recycle 425
  - 3.1.5 Heat Integration Imbalances 426
- 3.2 Subcooling: How It Impacts Towers 428
  - 3.2.1 Additional Internal Condensation and Reflux 428
  - 3.2.2 Less Loadings above Feed 429
  - 3.2.3 Trapping Lights and Quenching 429
  - 3.2.4 Others 430
- 3.3 Superheat: How It Impacts Towers 430

## 4. Tower Sizing and Material Selection Affect Performance 431

- 4.1 Undersizing Trays and Downcomers 431
- 4.2 Oversizing Trays 431
- 4.3 Tray Details Can Bottleneck Towers 433
- 4.4 Low Liquid Loads Can Be Troublesome 434
  - 4.4.1 Loss of Downcomer Seal 434
  - 4.4.2 Tray Dryout 435
- 4.5 Special Bubble-Cap Tray Problems 436
- 4.6 Misting 437
- 4.7 Undersizing Packings 437
- 4.8 Systems Where Packings Perform Different from Expectations 437

4.9	Packed Bed Too Long	438
4.10	Packing Supports Can Bottleneck Towers	439
4.11	Packing Hold-downs Are Sometimes Troublesome	440
4.12	Internals Unique to Packed Towers	440
4.13	Empty (Spray) Sections	440

## **5. Feed Entry Pitfalls in Tray Towers 441**

5.1	Does the Feed Enter the Correct Tray?	441
5.2	Feed Pipes Obstructing Downcomer Entrance	441
5.3	Feed Flash Can Choke Downcomers	441
5.4	Subcooled Feeds, Refluxes Are Not Always Trouble Free	442
5.5	Liquid and Unsuitable Distributors Do Not Work with Flashing Feeds	442
5.6	Flashing Feeds Require More Space	443
5.7	Uneven or Restrictive Liquid Split to Multipass Trays at Feeds and Pass Transitions	443
5.8	Oversized Feed Pipes	444
5.9	Plugged Distributor Holes	444
5.10	Low $\Delta P$ Trays Require Decent Distribution	445

## **6. Packed-Tower Liquid Distributors: Number 6 on the Top 10 Malfunctions 446**

6.1	Better Quality Distributors Improve Performance	446
6.1.1	Original Distributor Orifice or Unspecified	446
6.1.2	Original Distributor Weir Type	447
6.1.3	Original Distributor Spray Type	447
6.2	Plugged Distributors Do Not Distribute Well	448
6.2.1	Pan/Trough Orifice Distributors	448
6.2.2	Pipe Orifice Distributors	449
6.2.3	Spray Distributors	450
6.3	Overflow in Gravity Distributors: Death to Distribution	451
6.4	Feed Pipe Entry and Predistributor Problems	454
6.5	Poor Flashing Feed Entry Bottleneck Towers	455
6.6	Oversized Weep Holes Generate Undesirable Distribution	456
6.7	Damaged Distributors Do Not Distribute Well	457
6.7.1	Broken Flanges or Missing Spray Nozzles	457
6.7.2	Others	457
6.8	Hole Pattern and Liquid Heads Determine Irrigation Quality	458
6.9	Gravity Distributors Are Meant to Be Level	459
6.10	Hold-Down Can Interfere with Distribution	460
6.11	Liquid Mixing Is Needed in Large-Diameter Distributors	460
6.12	Notched Distributors Have Unique Problems	461
6.13	Others	461

**7. Vapor Maldistribution in Trays and Packings** **462**

---

- 7.1 Vapor Feed/Reboiler Return Maldistributes Vapor to Packing Above 462
  - 7.1.1 Chemical/Gas Plant Packed Towers 462
  - 7.1.2 Packed Refinery Main Fractionators 463
- 7.2 Experiences with Vapor Inlet Distribution Baffles 465
- 7.3 Packing Vapor Maldistribution at Intermediate Feeds and Chimney Trays 465
- 7.4 Vapor Maldistribution Is Detrimental in Tray Towers 466
  - 7.4.1 Vapor Cross-Flow Channeling 466
  - 7.4.2 Multipass Trays 467
  - 7.4.3 Others 467

**8. Tower Base Level and Reboiler Return: Number 2 on the Top 10 Malfunctions** **468**

---

- 8.1 Causes of High Base Level 468
  - 8.1.1 Faulty Level Measurement or Level Control 468
  - 8.1.2 Operation 469
  - 8.1.3 Excess Reboiler Pressure Drop 470
  - 8.1.4 Undersized Bottom Draw Nozzle or Bottom Line 470
  - 8.1.5 Others 470
- 8.2 High Base Level Causes Premature Tower Flood (No Tray/Packing Damage) 470
- 8.3 High Base Liquid Level Causes Tray/Packing Damage 471
- 8.4 Impingement by the Reboiler Return Inlet 472
  - 8.4.1 On Liquid Level 472
  - 8.4.2 On Instruments 473
  - 8.4.3 On Tower Wall 473
  - 8.4.4 Opposing Reboiler Return Lines 474
  - 8.4.5 On Trays 474
  - 8.4.6 On Seal Pan Overflow 474
- 8.5 Undersized Bottom Feed Line 475
- 8.6 Low Base Liquid Level 475
- 8.7 Issues with Tower Base Baffles 476
- 8.8 Vortexing 476

**9. Chimney Tray Malfunctions: Part of Number 7 on the Top 10 Malfunctions** **477**

---

- 9.1 Leakage 477
- 9.2 Problem with Liquid Removal, Downcomers, or Overflows 478
- 9.3 Thermal Expansion Causing Warping, Out-of-Levelness 479
- 9.4 Chimneys Impeding Liquid Flow to Outlet 480

9.5	Vapor from Chimneys Interfering with Incoming Liquid	480
9.6	Level Measurement Problems	481
9.7	Coking, Fouling, Freezing	482
9.8	Other Chimney Tray Issues	482

## **10. Drawoff Malfunctions (Non–Chimney Tray): Part of Number 7 on the Top 10 Malfunctions** **484**

---

10.1	Vapor Chokes Liquid Draw Lines	484
10.1.1	Insufficient Degassing	484
10.1.2	Excess Line Pressure Drop	485
10.1.3	Vortexing	486
10.2	Leak at Draw Tray Starves Draw	486
10.3	Draw Pans and Draw Lines Plug Up	488
10.4	Draw Tray Damage Affects Draw Rates	488
10.5	Undersized Side-Stripper Overhead Lines Restrict Draw Rates	488
10.6	Degassed Draw Pan Liquid Initiates Downcomer Backup Flood	489
10.7	Other Problems with Tower Liquid Draws	489
10.8	Liquid Entrainment in Vapor Side Draws	490
10.9	Reflux Drum Malfunctions	490
10.9.1	Reflux Drum Level Problems	490
10.9.2	Undersized or Plugged Product Lines	490
10.9.3	Two Liquid Phases	490

## **11. Tower Assembly Mishaps: Number 5 on the Top 10 Malfunctions** **491**

---

11.1	Incorrect Tray Assembly	491
11.2	Downcomer Clearance and Inlet Weir Malinstallation	491
11.3	Flow Passage Obstruction and Internals Misorientation at Tray Tower Feeds and Draws	492
11.4	Leaking Trays and Accumulator Trays	493
11.5	Bolts, Nuts, Clamps	493
11.6	Manways/Hatchways Left Unbolted	493
11.7	Materials of Construction Inferior to Those Specified	494
11.8	Debris Left in Tower or Piping	494
11.9	Packing Assembly Mishaps	495
11.9.1	Random	495
11.9.2	Structured	496
11.9.3	Grid	496
11.10	Fabrication and Installation Mishaps in Packing Distributors	496
11.11	Parts Not Fitting through Manholes	498
11.12	Auxiliary Heat Exchanger Fabrication and Assembly Mishaps	498
11.13	Auxiliary Piping Assembly Mishaps	498

## **12. Difficulties during Start-Up, Shutdown, Commissioning, and Abnormal Operation: Number 4 on the Top 10 Malfunctions** **499**

---

12.1	Blinding/Unblinding Lines	499	
12.2	Backflow	500	
12.3	Dead-Pocket Accumulation and Release of Trapped Materials		501
12.4	Purging	501	
12.5	Pressuring and Depressuring	502	
12.6	Washing	502	
12.7	On-Line Washes	504	
12.8	Steam and Water Operations	506	
12.9	Overheating	506	
12.10	Cooling	507	
12.11	Overchilling	507	
12.12	Water Removal	508	
	12.12.1 Draining at Low Points	508	
	12.12.2 Oil Circulation	508	
	12.12.3 Condensation of Steam Purges	508	
	12.12.4 Dehydration by Other Procedures	508	
12.13	Start-Up and Initial Operation	509	
	12.13.1 Total-Reflux Operation	509	
	12.13.2 Adding Components That Smooth Start-Up	509	
	12.13.3 Siphoning	509	
	12.13.4 Pressure Control at Start-Up	510	
12.14	Confined Space and Manhole Hazards	510	

## **13. Water-Induced Pressure Surges: Part of Number 3 on the Top 10 Malfunctions** **512**

---

13.1	Water in Feed and Slop	512	
13.2	Accumulated Water in Transfer Line to Tower and in Heater Passes	513	
13.3	Water Accumulation in Dead Pockets	513	
13.4	Water Pockets in Pump or Spare Pump Lines	514	
13.5	Undrained Stripping Steam Lines	515	
13.6	Condensed Steam or Refluxed Water Reaching Hot Section	516	
13.7	Oil Entering Water-Filled Region	517	

## **14. Explosions, Fires, and Chemical Releases: Number 10 on the Top 10 Malfunctions** **518**

---

14.1	Explosions Due to Decomposition Reactions	518	
	14.1.1 Ethylene Oxide Towers	518	
	14.1.2 Peroxide Towers	519	
	14.1.3 Nitro Compound Towers	520	
	14.1.4 Other Unstable-Chemical Towers	521	



14.2	Explosions Due to Violent Reactions	523
14.3	Explosions and Fires Due to Line Fracture	524
14.3.1	C <sub>3</sub> –C <sub>4</sub> Hydrocarbons	524
14.3.2	Overchilling	525
14.3.3	Water Freeze	526
14.3.4	Other	527
14.4	Explosions Due to Trapped Hydrocarbon or Chemical Release	527
14.5	Explosions Induced by Commissioning Operations	528
14.6	Packing Fires	529
14.6.1	Initiated by Hot Work Above Steel Packing	529
14.6.2	Pyrophoric Deposits Played a Major Role, Steel Packing	530
14.6.3	Tower Manholes Opened While Packing Hot, Steel Packing	532
14.6.4	Others, Steel Packing Fires	532
14.6.5	Titanium, Zirconium Packing Fires	533
14.7	Fires Due to Opening Tower before Cooling or Combustible Removal	533
14.8	Fires Caused by Backflow	534
14.9	Fires by Other Causes	535
14.10	Chemical Releases by Backflow	536
14.11	Trapped Chemicals Released	536
14.12	Relief, Venting, Draining, Blowdown to Atmosphere	537

## **15. Undesired Reactions in Towers 539**

---

15.1	Excessive Bottom Temperature/Pressure	539
15.2	Hot Spots	539
15.3	Concentration or Entry of Reactive Chemical	539
15.4	Chemicals from Commissioning	540
15.5	Catalyst Fines, Rust, Tower Materials Promote Reaction	540
15.6	Long Residence Times	541
15.7	Inhibitor Problems	541
15.8	Air Leaks Promote Tower Reactions	542
15.9	Impurity in Product Causes Reaction Downstream	542

## **16. Foaming 543**

---

16.1	What Causes or Promotes Foaming?	543
16.1.1	Solids, Corrosion Products	543
16.1.2	Corrosion and Fouling Inhibitors, Additives, and Impurities	544
16.1.3	Hydrocarbon Condensation into Aqueous Solutions	545
16.1.4	Wrong Filter Elements	546
16.1.5	Rapid Pressure Reduction	546
16.1.6	Proximity to Solution Plait Point	546

16.2	What Are Foams Sensitive To?	546
16.2.1	Feedstock	546
16.2.2	Temperature	547
16.2.3	Pressure	547
16.3	Laboratory Tests	547
16.3.1	Sample Shake, Air Bubbling	547
16.3.2	Oldershaw Column	547
16.3.3	Foam Test Apparatus	548
16.3.4	At Plant Conditions	548
16.4	Antifoam Injection	548
16.4.1	Effective Only at the Correct Quantity/Concentration	548
16.4.2	Some Antifoams Are More Effective Than Others	549
16.4.3	Batch Injection Often Works, But Continuous Can Be Better	549
16.4.4	Correct Dispersal Is Important, Too	550
16.4.5	Antifoam Is Sometimes Adsorbed on Carbon Beds	550
16.4.6	Other Successful Antifoam Experiences	550
16.4.7	Sometimes Antifoam Is Less Effective	551
16.5	System Cleanup Mitigates Foaming	551
16.5.1	Improving Filtration	551
16.5.2	Carbon Beds Mitigate Foaming But Can Adsorb Antifoam	553
16.5.3	Removing Hydrocarbons from Aqueous Solvents	553
16.5.4	Changing Absorber Solvent	553
16.5.5	Other Contaminant Removal Techniques	554
16.6	Hardware Changes Can Debottleneck Foaming Towers	555
16.6.1	Larger Downcomers	555
16.6.2	Smaller Downcomer Backup (Lower Pressure Drop, Larger Clearances)	556
16.6.3	More Tray Spacing	556
16.6.4	Removing Top Two Trays Does Not Help	556
16.6.5	Trays Versus Packings	556
16.6.6	Larger Packings, High-Open-Area Distributors Help	557
16.6.7	Increased Agitation	557
16.6.8	Larger Tower	557
16.6.9	Reducing Base Level	557

## **17. The Tower as a Filter: Part A. Causes of Plugging—Number 1 on the Top 10 Malfunctions**

558

---

17.1	Piping Scale/Corrosion Products	558
17.2	Salting Out/Precipitation	559
17.3	Polymer/Reaction Products	560
17.4	Solids/Entrainment in the Feed	561
17.5	Oil Leak	561

- 17.6 Poor Shutdown Wash/Flush 562
- 17.7 Entrainment or Drying at Low Liquid Rates 562
- 17.8 Others 562

## **18. The Tower as a Filter: Part B. Locations of Plugging—Number 1 on the Top 10 Malfunctions** **563**

---

- 18.1 Trays 563
- 18.2 Downcomers 564
- 18.3 Packings 565
- 18.4 How Packings and Trays Compare on Plugging Resistance 565
  - 18.4.1 Trays versus Trays 565
  - 18.4.2 Trays versus Packings 566
  - 18.4.3 Packings versus Packings 567
- 18.5 Limited Zone Only 567
- 18.6 Draw, Exchanger, and Vent Lines 569
- 18.7 Feed and Inlet Lines 570
- 18.8 Instrument Lines 570

## **19. Coking: Part of Number 1 on Tower Top 10 Malfunctions** **571**

---

- 19.1 Insufficient Wash Flow Rate, Refinery Vacuum Towers 571
- 19.2 Other Causes, Refinery Vacuum Towers 572
- 19.3 Slurry Section, FCC Fractionators 573
- 19.4 Other Refinery Fractionators 574
- 19.5 Nonrefinery Fractionators 574

## **20. Leaks** **575**

---

- 20.1 Pump, Compressor 575
- 20.2 Heat Exchanger 575
  - 20.2.1 Reboiler Tube 575
  - 20.2.2 Condenser Tube 576
  - 20.2.3 Auxiliary Heat Exchanger (Preheater, Pumparound) 576
- 20.3 Chemicals to/from Other Equipment 577
  - 20.3.1 Leaking from Tower 577
  - 20.3.2 Leaking into Tower 577
  - 20.3.3 Product to Product 578
- 20.4 Atmospheric 578
  - 20.4.1 Chemicals to Atmosphere 578
  - 20.4.2 Air into Tower 579

## **21. Relief and Failure** **580**

---

- 21.1 Relief Requirements 580
- 21.2 Controls That Affect Relief Requirements and Frequency 580
- 21.3 Relief Causes Tower Damage, Shifts Deposits 581

21.4	Overpressure Due to Component Entry	581
21.5	Relief Protection Absent or Inadequate	582
21.6	Line Ruptures	583
21.7	All Indication Lost When Instrument Tap Plugged	584
21.8	Trips Not Activating or Incorrectly Set	584
21.9	Pump Failure	585
21.10	Loss of Vacuum	585
21.11	Power Loss	585

**22. Tray, Packing, and Tower Damage: Part of Number 3 on the Top 10 Malfunctions** **586**

---

22.1	Vacuum	586
22.2	Insufficient Uplift Resistance	587
22.3	Uplift Due to Poor Tightening during Assembly	587
22.4	Uplift Due to Rapid Upward Gas Surge	589
22.5	Valves Popping Out	590
22.6	Downward Force on Trays	590
22.7	Trays below Feed Bent Up, above Bent Down and Vice Versa	591
22.8	Downcomers Compressed, Bowed, Fallen	592
22.9	Uplift of Cartridge Trays	593
22.10	Flow-Induced Vibrations	593
22.11	Compressor Surge	594
22.12	Packing Carryover	595
22.13	Melting, Breakage of Plastic Packing	595
22.14	Damage to Ceramic Packing	595
22.15	Damage to Other Packings	595

**23. Reboilers That Did Not Work: Number 9 on the Top 10 Malfunctions** **596**

---

23.1	Circulating Thermosiphon Reboilers	596
23.1.1	Excess Circulation	596
23.1.2	Insufficient Circulation	596
23.1.3	Insufficient $\Delta T$ , Pinching	596
23.1.4	Surging	596
23.1.5	Velocities Too Low in Vertical Thermosiphons	597
23.1.6	Problems Unique to Horizontal Thermosiphons	597
23.2	Once-Through Thermosiphon Reboilers	597
23.2.1	Leaking Draw Tray or Draw Pan	597
23.2.2	No Vaporization/Thermosiphon	598
23.2.3	Slug Flow in Outlet Line	599
23.3	Forced-Circulation Reboilers	599
23.4	Kettle Reboilers	599
23.4.1	Excess $\Delta P$ in Circuit	599
23.4.2	Poor Liquid Spread	601
23.4.3	Liquid Level above Overflow Baffle	602

23.5	Internal Reboilers	602	
23.6	Kettle and Thermosiphon Reboilers in Series	603	
23.7	Side Reboilers	603	
	23.7.1 Inability to Start	603	
	23.7.2 Liquid Draw and Vapor Return Problems	603	
	23.7.3 Hydrates	603	
	23.7.4 Pinching	604	
	23.7.5 Control Issues	604	
23.8	All Reboilers, Boiling Side	604	
	23.8.1 Debris/Deposits in Reboiler Lines	604	
	23.8.2 Undersizing	604	
	23.8.3 Film Boiling	604	
23.9	All Reboilers, Condensing Side	605	
	23.9.1 Non condensables in Heating Medium	605	
	23.9.2 Loss of Condensate Seal	605	
	23.9.3 Condensate Draining Problems	606	
	23.9.4 Vapor/Steam Supply Bottleneck	606	
<b>24. Condensers That Did Not Work</b>			<b>607</b>
24.1	Inerts Blanketing	607	
	24.1.1 Inadequate Venting	607	
	24.1.2 Excess Lights in Feed	608	
24.2	Inadequate Condensate Removal	608	
	24.2.1 Undersized Condensate Lines	608	
	24.2.2 Exchanger Design	609	
24.3	Unexpected Condensation Heat Curve	609	
24.4	Problems with Condenser Hardware	610	
24.5	Maldistribution between Parallel Condensers	611	
24.6	Flooding/Entrainment in Partial Condensers	611	
24.7	Interaction with Vacuum and Recompression Equipment	612	
24.8	Others	612	
<b>25. Misleading Measurements: Number 8 on the Top 10 Malfunctions</b>			<b>613</b>
25.1	Incorrect Readings	613	
25.2	Meter or Taps Fouled or Plugged	614	
25.3	Missing Meter	615	
25.4	Incorrect Meter Location	615	
25.5	Problems with Meter and Meter Tubing Installation	616	
	25.5.1 Incorrect Meter Installation	616	
	25.5.2 Instrument Tubing Problems	616	
25.6	Incorrect Meter Calibration, Meter Factor	617	
25.7	Level Instrument Fooled	617	
	25.7.1 By Froth or Foam	617	
	25.7.2 By Oil Accumulation above Aqueous Level	618	
	25.7.3 By Lights	619	

25.7.4	By Radioactivity (Nucleonic Meter)	619
25.7.5	Interface-Level Metering Problems	619
25.8	Meter Readings Ignored	619
25.9	Electric Storm Causes Signal Failure	619

## **26. Control System Assembly Difficulties 620**

---

26.1	No Material Balance Control	620
26.2	Controlling Two Temperatures/Compositions Simultaneously Produces Interaction	621
26.3	Problems with the Common Control Schemes, No Side Draws	622
26.3.1	Boil-Up on TC/AC, Reflux on FC	622
26.3.2	Boil-Up on FC, Reflux on TC/AC	623
26.3.3	Boil-Up on FC, Reflux on LC	624
26.3.4	Boil-Up on LC, Bottoms on TC/AC	625
26.3.5	Reflux on Base LC, Bottoms on TC/AC	626
26.4	Problems with Side-Draw Controls	626
26.4.1	Small Reflux below Liquid Draw Should Not Be on Level or Difference Control	626
26.4.2	Incomplete Material Balance Control with Liquid Draw	628
26.4.3	Steam Spikes with Liquid Draw	628
26.4.4	Internal Vapor Control makes or Breaks Vapor Draw Control	628
26.4.5	Others	628

## **27. Where Do Temperature and Composition Controls Go Wrong? 629**

---

27.1	Temperature Control	629
27.1.1	No Good Temperature Control Tray	629
27.1.2	Best Control Tray	630
27.1.3	Fooling by Nonkeys	630
27.1.4	Averaging (Including Double Differential)	631
27.1.5	Azeotropic Distillation	631
27.1.6	Extractive Distillation	631
27.1.7	Other	632
27.2	Pressure-Compensated Temperature Controls	632
27.2.1	$\Delta T$ Control	632
27.2.2	Other Pressure Compensation	633
27.3	Analyzer Control	633
27.3.1	Obtaining a Valid Analysis for Control	633
27.3.2	Long Lags and High Off-Line Times	633
27.3.3	Intermittent Analysis	634
27.3.4	Handling Feed Fluctuations	635
27.3.5	Analyzer-Temperature Control Cascade	635
27.3.6	Analyzer On Next Tower	635

**28. Misbehaved Pressure, Condenser, Reboiler, and Preheater Controls 636**

28.1	Pressure Controls by Vapor Flow Variations	636
28.2	Flooded Condenser Pressure Controls	637
28.2.1	Valve in the Condensate, Unflooded Drum	637
28.2.2	Flooded Drum	637
28.2.3	Hot-Vapor Bypass	637
28.2.4	Valve in the Vapor to the Condenser	639
28.3	Coolant Throttling Pressure Controls	640
28.3.1	Cooling-Water Throttling	640
28.3.2	Manipulating Airflow	640
28.3.3	Steam Generator Overhead Condenser	640
28.3.4	Controlling Cooling-Water Supply Temperature	640
28.4	Pressure Control Signal	641
28.4.1	From Tower or from Reflux Drum?	641
28.4.2	Controlling Pressure via Condensate Temperature	641
28.5	Throttling Steam/Vapor to Reboiler or Preheater	641
28.6	Throttling Condensate from Reboiler	642
28.7	Preheater Controls	643

**29. Miscellaneous Control Problems 644**

29.1	Interaction with the Process	644
29.2	$\Delta P$ Control	644
29.3	Flood Controls and Indicators	644
29.4	Batch Distillation Control	645
29.5	Problems in the Control Engineer's Domain	645
29.6	Advanced Controls Problems	646
29.6.1	Updating Multivariable Controls	646
29.6.2	Advanced Controls Fooled by Bad Measurements	646
29.6.3	Issues with Model Inaccuracies	647
29.6.4	Effect of Power Dips	647
29.6.5	Experiences with Composition Predictors in Multivariable Controls	647

**References 649****Index 669****About the Author 713**

This page intentionally left blank



# Preface

*“To every problem, there’s always an easy solution—neat, plausible, and wrong.”*

—Mencken’s Maxim

The last half-century has seen tremendous progress in distillation technology. The introduction of high-speed computers revolutionized the design, control, and operation of distillation towers. Invention and innovation in tower internals enhanced tower capacity and efficiency beyond previously conceived limits. Gamma scans and laser-guided pyrometers have provided troubleshooters with tools of which, not-so-long-ago, they would only dream. With all these advances, one would expect the failure rate in distillation towers to be on the decline, maybe heading towards extinction as we enter the 21<sup>st</sup> century. Our recent survey of distillation failures (255) brought disappointing news: Distillation failures are not on the path to extinction. Instead, the tower failure rate is on the rise and accelerating.

Our survey further showed that the rise is not because distillation is moving into new, uncharted frontiers. By far, the bulk of the failures have been repetitions of previous ones. In some cases, the literature describes 10–20 repetitions of the same failure. And for every case that is reported, there are tens, maybe hundreds, that are not.

In the late 1980s, I increased tray hole areas in one distillation tower in an attempt to gain capacity. Due to vapor cross flow channeling, a mechanism unknown at the time, the debottleneck went sour and we lost 5% capacity. Half a year of extensive troubleshooting, gamma scans, and tests taught us what went wrong and how to regain the lost capacity. We published extensively on the phenomenon and how to avoid. A decade later, I returned to investigate why another debottleneck (this time by others) went sour at the same unit. The tower I previously struggled with was replaced by a larger one, but the next tower in the sequence (almost the same hydraulics as the first) was debottlenecked . . . by increasing tray hole areas!

It dawned on me how short a memory the process industries have. People move on, the lessons get forgotten, and the same mistakes are repeated. It took only one decade to forget. Indeed, people moved on: only one person (beside me) that experienced the 1980s debottleneck was involved in the 1990s efforts. This person actually questioned

the debottleneck proposal, but was overruled by those who did not believe it will happen again.

Likewise, many experiences are repeatedly reported in the literature. Over the last two decades, there has been about one published case history per year of a tower flooding prematurely due to liquid level rising above the reboiler return nozzle, or of a kettle reboiler bottleneck due to an incorrectly compiled force balance. One would think that had we learned from the first case, all the repetitions could have been avoided. And again, for every case that is reported, there are tens, maybe hundreds that are not.

Why are we failing to learn from past lessons? Mergers and cost-cuts have retired many of the experienced troubleshooters and thinly spread the others. The literature offers little to bridge the experience gap. In the era of information explosion, databases, and computerized searches, finding the appropriate information in due time has become like finding a needle in an evergrowing haystack. To locate a useful reference, one needs to click away a huge volume of wayward leads. Further, cost-cutting measures led to library closures and to curtailed circulation and availability of some prime sources of information, such as, AIChE meeting papers.

The purpose of this book is pick the needles out of the haystack. The book collects lessons from past experiences and puts them in the hands of troubleshooters in a usable form. The book is made up of two parts: the first is a collection of “war stories,” with the detailed problems and solutions. The second part is a database mega-table which presents summaries of all the “war stories” I managed to find in the literature. The summaries include some key distillation-related morals. For each of these, the literature reference is described fully, so readers can seek more details. Many of the case histories could be described under more than one heading, so extensive cross references have been included.

If an incident that happened in your plant is described, you may notice that some details could have changed. Sometimes, this was done to make it more difficult for people to tell where the incident occurred. At other times, this was done to simplify the story without affecting the key lessons. Sometimes, the incident was written up several years after it occurred, and memories of some details faded away. Sometimes, and this is the most likely reason, the case history did not happen in your plant at all. Another plant had a similar incident.

The case histories and lessons drawn are described to the best of my and the contributors' knowledge and in good faith, but do not always correctly reflect the problems and solutions. Many times I thought I knew the answer, possibly even solved the problem, only to be humbled by new light or another experience later. The experiences and lessons in the book are not meant to be followed blindly. They are meant to be taken as stories told in good faith, and to the best of knowledge and understanding of the author or contributor. We welcome any comments that either affirm or challenge our perception and understanding.

If you picked the book, you expressed interest in learning from past experiences. This learning is an essential major step along the path traveled by a good troubleshooter or designer. Should you select this path, be prepared for many sleepless nights in the plant, endless worries as to whether you have the right answer, tests that will

shatter your favorite theories, and many humbling experiences. Yet, you will share the glory when your fix or design solves a problem where others failed. You will enjoy harnessing the forces of nature into a beneficial purpose. Last but not least, you will experience the electric excitement of the “moments of insight,” when all the facts you have been struggling with for months suddenly fall together into a simple explanation. I hope this book helps to get you there.

HENRY Z. KISTER

*March 2006*

This page intentionally left blank

# Acknowledgments

Many of the case histories reported in this book have been invaluable contributions from colleagues and friends who kindly and enthusiastically supported this book. Many of the contributors elected to remain anonymous. Kind thanks are due to all contributors. Special thanks are due to those who contributed multiple case histories, and to those whose names do not appear in print. To those behind-the-scenes friends, I extends special appreciation and gratitude.

Writing this book required breaking away from some of the everyday work demands. Special thanks are due to Fluor Corporation, particularly to my supervisors, Walter Stupin and Paul Walker, for their backing, support and encouragement of this book-writing effort, going to great lengths to make it happen.

Recognition is due to my mentors who, over the years, encouraged my work, immensely contributed to my achievements, and taught me much about distillation and engineering: To my life-long mentor, Walter Stupin, who mentored and encouraged my work, throughout my career at C F Braun and later at Fluor, being a ceaseless source of inspiration behind my books and technical achievements; Paul Walker, Fluor, whose warm encouragement and support have been the perfect motivators for professional excellence and achievement; Professor Ian Doig, University of NSW, who inspired me over the years, showed me the practical side of distillation, and guided me over a crisis early in my career; Reno Zack, who enthusiastically encouraged and inspired my achievements throughout my career at C F Braun; Dick Harris and Trevor Whalley, who taught me about practical distillation and encouraged my work and professional pursuits at ICI Australia; and Jack Hull, Tak Yanagi, and Jim Gosnell, who were sources of teaching and inspiration at C F Braun. The list could go on, and I express special thanks to all that encouraged, inspired, and contributed to my work over the years. Much of my mentors' teachings found their way into the following pages.

Special thanks are due to family members and close friends who have helped, supported and encouraged my work—my mother, Dr. Helen Kister, my father, Dr. John Kister, and Isabel Wu—your help and inspiration illuminated my path over the years.

Last but not least, special thanks are due to Mireille Grey and Stan Okimoto at Fluor, who flawlessly and tirelessly converted my handwritten scrawl into a typed manuscript, putting up with my endless changes and reformat.

H.Z.K.

This page intentionally left blank